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FINAL REPORT
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"Fluid Flow and Infiltration in Structured Fibrous Porous Media

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DISCLAIMER

Summary Report for Grant 15510-F100
"Fluid Flow and Infiltration through Structured Fibrous Media"

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1. EXECUTIVE SUMMARY

In the course of this grant we investigated computationally the permeability (K) of fibrous media in which the fibers are found in some structured form, mainly in the form of bundles. We investigated the above in the absence and presence of fluid inertia (Re=0 and Re>0 respectively). The award amount was chiefly used to support the PhD studies of Dr. B. Markicevic, who successfully defended his PhD Thesis in late August 2001. In the course of this program we also carried out collaborative research with the group of Dr. Edward Dendy, T-Division, Los Alamos National Laboratory and hosted three (3) REU undergraduate students to work in our labs on related problems. In all we published (9) papers in refereed technical Journals and presented in (5) meetings, some of which included proceedings with full-length papers. The technical results of our work under this grant are detailed in the attached papers, which appear as Appendix (II). In summary, the results of this project can be subdivided in four categories:

(1) We developed generalized correlations for the permeability of arrays of fiber bundles of circular and elliptical cross-sections (publications [1],[4],[5],[6])

(2) We investigated the effect of fluid inertia on the permeability of fibrous media and proposed a modification to the well-known Forscheimer equation to account for the nature of fibrous systems (publication [3])

(3) We examined systems in which various types of fiber bundles alternate in a fabric and proposed rules by which their permeability can be predicted (publications [8],[9])

(4) Examined the effect of variations in fabric geometry on permeability and compared computational findings with existing theoretical models (publications [2],[7])

The list of Journal publications and conference presentations can be found in Appendix (I). The outline of detailed outcomes follows:

2. EDUCATIONAL OUTCOMES

This award supported the PhD studied of Dr. B. Markicevic, who completed his degree requirements in the Fall of 2001. Immediately following his Thesis defense Dr. Markicevic accepted a two-year post doctoral appointment with the Center for Composite Materials at the University of Delaware, USA.

In addition several undergraduate students carried out research in our laboratories under this program. Specifically the work of Erin Gravel appeared in publication ([6]) and presentations ([5] and [3]) in Appendix (I), the work of Shanna Barwick in publication ([5]), while the work of Joel Desjardins in presentation ([1]).

3. COLLABORATIVE OUTCOMES

This award allowed us to work cooperatively with the group of Dr. Dendy at LANL. The results of this collaboration appeared as publications 5 and 3 in Appendix (I). We also wrote and submitted a joint proposal under a 1999 DOE Call on Complex and Collective Phenomena; that proposal was not funded.

4. RESEARCH OUTCOMES

These are shown in detail in the extensive Appendix (II) attached to this report. In part as a result of this grant the PI and his group have developed the depth of work and expertise that enabled them to compete successfully and obtain an NSF grant in the topic of liquid molding of composites (9/2005-9-2008).

APPENDIX (I):
List of papers in Refereed Journals and in Conference Proceedings

I.a Refereed Journals

9 B. Markicevic and T.D. Papathanasiou, "An Explicit Physics-Based Model for the Transverse Permeability of Multi-Material Dual Porosity Fibrous Media", Transport in Porous Media, **53**(3), 265-280, 2003

8 B. Markicevic and T.D. Papathanasiou, "A model for the transverse permeability of bi-material layered fibrous preforms", Polymer Composites, **24**(1), 68-82, 2003

7 B. Markicevic and T.D. Papathanasiou, "On the Apparent Permeability of Regular Arrays of non-Uniform Fibers", Physics of Fluids,**14**(9), 3347-3349, 2002

6 E.M. Gravel and T.D. Papathanasiou, "Development of permeability models for saturated fluid flow across arrays of fiber clusters", Advanced Composites Letters, **11**(3), 123-130, 2002

5 T.D. Papathanasiou, E. Gravel, S.C. Barwick and E.D. Dendy, "Non-isotropic structured fibrous media: The permeability of regular arrays of fiber bundles of elliptical cross-section", Polymer Composites, **23**(4), 520-529, 2002

4 T.D. Papathanasiou, "Flow across structured fiber bundles: A dimensionless correlation", International Journal of Multiphase Flow, **27**, 1451-1461, 2001

3 T.D. Papathanasiou, B. Markicevic and E. Dendy, "A computational evaluation of the Ergun and Forchheimer equations for fibrous media", Physics of Fluids, **13**(10), 2795-2804, 2001

2 T.D. Papathanasiou, "The hydraulic permeability of periodic arrays of cylinders of varying size", Journal of Porous Media, **4**(4), 323-336, 2001

1 B. Markicevic and T.D. Papathanasiou, "The Hydraulic Permeability of Dual Porosity Fibrous Media", Journal of Reinforced Plastics and Composites, **20**(10), 871-880, 2001

I.b Conference Proceedings

5 E.M. Gravel and T.D. Papathanasiou, "Development of permeability models for saturated fluid flow across arrays of fiber clusters", 2nd National Conference on Composites - Hellas-Comp-2000, University of Patras, Greece, June 2001

4 B. Markicevic & T.D. Papathanasiou, "The effect of fiber size and fluid inertia on the permeability of fibrous media", Society of Engineering Science (SES) Annual Meeting, Columbia, SC, October 2000

3 E. Gravel & T.D. Papathanasiou, "A general correlation for the hydraulic permeability of dual porosity fibrous media", in "Rheology and Fluid Mechanics of NonLinear Materials-2000", Siginer & De Kee (Eds.), pg. 65-70. Also presented at 2000 ASME Annual Meeting, October 2000, Orlando, FL (invited)

2 T.D. Papathanasiou and B. Markicevic, "The Hydraulic Permeability of Dual Porosity Fibrous Preforms", Society of Plastics Engineers Annual Conference, ANTEC-2000, Orlando, FL, May 2000

1 B. Markicevic, J. Desjardins & T.D. Papathanasiou, "The Influence of Lattice Inhomogeneity and Fluid Inertia on the Hydraulic Permeability of Fibrous Preforms", ESAFORM-2000 Conference on Materials Forming Processes, Session "Numerical methods and techniques", Stuttgart, Germany, April 2000